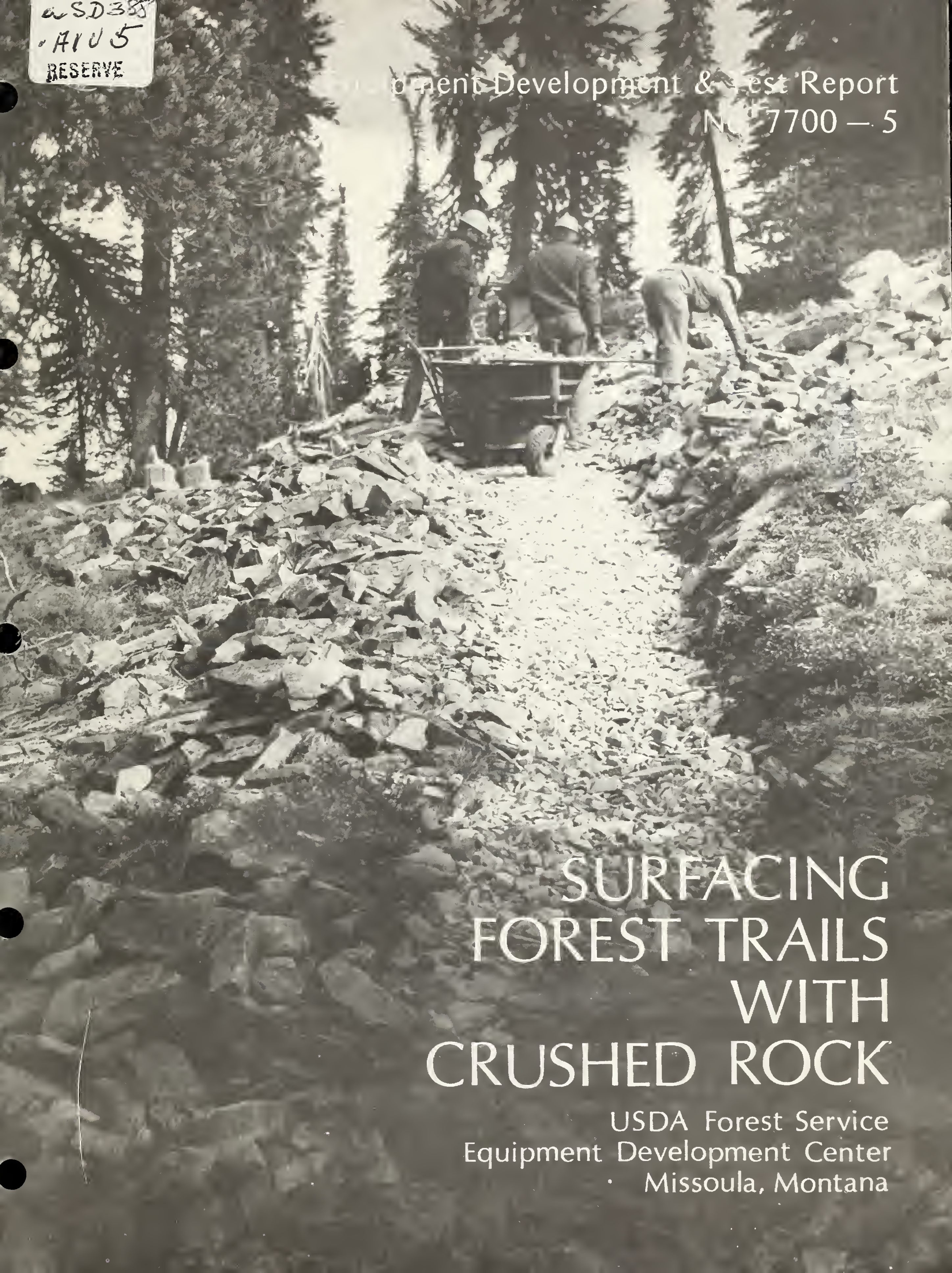

Equipment Development & Test Report
No. 7700 — 5

SURFACING FOREST TRAILS WITH CRUSHED ROCK

USDA Forest Service
Equipment Development Center
Missoula, Montana

Equipment Development and Test Report
No. 7700-5

2001

Surfacing Forest Trails with Crushed Rock

January 1975

USDA—Forest Service
Equipment Development Center
Missoula, Mont.

ACKNOWLEDGMENTS

The Equipment Development Center, Missoula, Mont., is indebted to the following organizations for assistance in designing, testing, and evaluating the equipment and procedures described in this report:

Regional Office, Pacific Northwest Region, Division of Engineering; Wallowa-Whitman National Forest, Baker Ranger District, Baker, Oreg.; Lolo National Forest, Plains Ranger District, Plains, Mont.; Bitterroot National Forest, Darby Ranger District, Darby, Mont.; Medicine Bow National Forest, Bow River Ranger District, Medicine Bow, Wyo.

ABSTRACT

Heavy traffic by shod horses and mules can cause portions of forest trails to deteriorate rapidly. Where suitable rock exists for crushing, a layer of crushed rock is a fast and relatively cheap method to repair trails and increase trail durability.

In 1972, a rock crusher and two different models of self-propelled rock carriers were evaluated for crushing, transporting, and spreading rock. Surfacing rates and costs were calculated for three methods of application. The machines evaluated proved sturdy and practical. It was found that crushing rock laying along the trail was the fastest and cheapest method of application.

Key Words: trails, trail surfacing, equipment engineering, construction materials, rock crusher, rock carrier.

A report written under ED&T Project No. 2101 on ED&T Project No. 1765, Durable Trail Treads, sponsored by the Division of Engineering.

CONTENTS

ILLUSTRATIONS

Figure | Page

TABLES

Table | Page

INTRODUCTION

Horse traffic, increasing at the rate of 10 to 15 percent a year on some Forest Service trails, can rapidly deteriorate trail tread. Trails needing only minor maintenance when traveled by a few head of stock each year, can develop chronic trouble spots requiring expensive maintenance and reconstruction when traffic builds to several thousand head annually.

In 1967, at the suggestion of the Pacific Northwest Region, the Missoula Center began evaluating various methods to improve forest trail durability. A study of alternatives indicated that a layer of crushed rock placed on the trail surface would increase tread life. Because crushed rock has angular edges that lock together and form a stable surface, it is superior to gravel, which is round and tends to roll. Also, crushed rock can be more economical than binders such as gunnite, asphalt, plastic, and soil cement, and it harmonizes with natural surroundings better than any other material considered.

The Missoula Center built a self-propelled rock crusher by mounting a commercial ore crusher on a custom-built chassis. This prototype was tried in several western Regions during 1969. Rock was moved and spread with two carriers manufactured by private firms. During this trial period, the crusher and carriers were improved.

In 1972, the Missoula Center evaluated the improved crusher and carriers on the Darby District of the Bitterroot National Forest. Purpose of the work was to compile basic data on surfacing rates and costs. Three different methods of application were considered: (1) crushing rock lying along the trail, (2) hauling rock crushed at a good rock source to the repair site, and (3) hauling whole rock to the repair site and crushing it there as the crusher moved along the trail.

This report evaluates the equipment and recommends the most efficient methods for spreading crushed rock on forest trails. The report emphasizes production data and should be valuable to any field unit interested in surfacing portions of trails.

EQUIPMENT

Rock Crusher

The rock crusher is a small ore crusher manufactured by the Denver Equipment Co., Denver, Colo., and mounted on a chassis designed by the Center. A 12-hp engine drives the crusher and turns the two rear wheels through a hydraulic motor mounted on each wheel; a single front wheel steers the machine. The chassis can be raised hydraulically on the two rear wheels so crushed rock can flow freely from the crusher. General features are shown in figure 1.

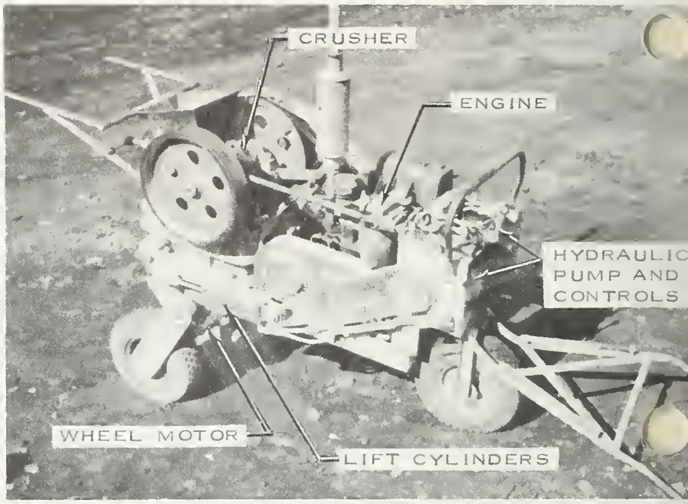

Figure 1.–Rock crusher designed to travel forest trails.

Picus Carrier

The carrier was built by Picus Industries, Portland, Oreg., to haul crushed rock over forest trails. It is powered by a 5-hp engine, and has 3 speeds forward and 1 reverse. Three drive wheels at the rear propel the carrier; a caster-mounted wheel in front supports some of the load and makes it easier to guide. A Center modification raised the front handlebars 7 inches for operator comfort. Rock is unloaded through an adjustable "belly dump." Two men must operate the carrier. Major components are identified in figure 2.

Figure 2.–Picus carrier designed to haul rock on trails.

Toter (Mark VI)

The Toter is a track-mounted carrier built by the Washington Scale Co., Yakima, Wash., (fig. 3). It is equipped with a 5-hp engine, 3-speed transmission (including reverse), and a clutch-brake steering system. The machine is 23 inches wide, track to track, and can operate on a trail of that width. It is driven by one man.

The Center modified an older model Toter to make it comparable to newer models. The dump box was custom built by the manufacturer with the bottom reinforced to withstand heavy loads. An adjustable gate at the front of the box controls rock flow. A caster wheel controls how far the box tips downward. To spread rock, the box is rolled forward; as the box rolls, it rotates down under its own weight until the caster wheel meets the trail. The gate opens and spreading begins.

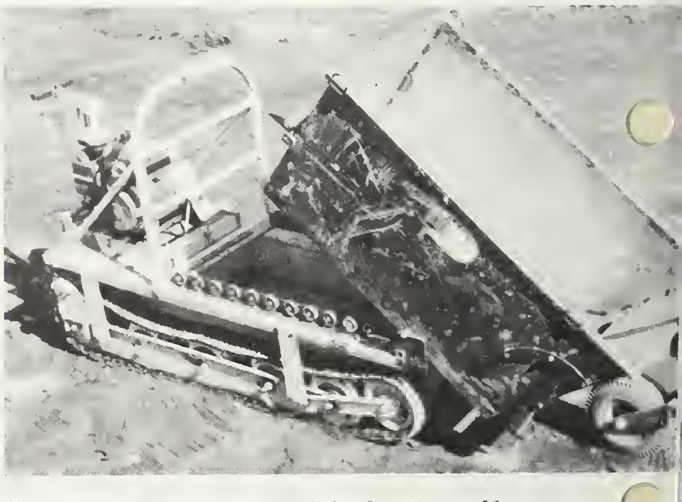

Figure 3.–Toter carrier used for hauling rock.

TEST SITES

Tests were conducted on the Sleeping Child Trail 105 and the North Shore Trail around Lake Como, both on the Darby District of the Bitterroot National Forest. The trails were selected because of ample rock supply, easy access, and varied surfaces. Sleeping Child Trail (fig. 4) follows a creek up a rough, narrow canyon and passes through several rock slides. It is narrow in spots; rocks and roots protrude above the trail surface, and in many places the trail slopes toward the outside of the tread. Several steep pitches in grade also slope outward.

The North Shore Trail (fig. 5) around Lake Como runs about 100 feet above the shoreline. Generally, the trail is wide and slopes toward the outside of the tread; however, there are several narrow spots. The trail is rough where it passes through rock slides.

Figure 4.–Section of Sleeping Child Trail surfaced with crushed rock.

TEST METHODS

The rock crusher and the Picus carrier were tested on both trails; the Toter was tested only on the North Shore Trail. Data were gathered on crushing rates, travel speeds, operating costs, and other parameters required to calculate surfacing rates and costs. Three methods of applying crushed rock to the trail were considered: (1) crushing rock laying along the trail; (2) hauling rock crushed at a good rock source to the work site; and (3) hauling rock to the work site and crushing it there. Notes were taken on factors influencing performance, such as trail conditions, rock sources, maintenance, and safety.

Center personnel experienced in operating the crusher and carriers ran the equipment and gathered data. During the test crew size varied from two to three men. (Field operations have demonstrated that it is usually most efficient to operate with a three-man crew.) One man operated the crusher and two men loaded and hauled rock with the Picus. Only one man operated the Toter. When the crusher operator crushed a load faster than the carriers could remove it, he assisted in loading the carriers; when the crusher could not keep up, the carrier operators helped gather rock for the crusher.

Figure 5.–Section of North Shore Trail.

EQUIPMENT PERFORMANCE

Crushing

Crushing rate for both trails averaged about 1.11 cubic yards per hour with the crusher jaws set for a ¾-inch opening. This figure was based on 47 cubic yards of crushed rock taken from slide rock areas, dry streambeds, and a lakebed. Rock hardness was comparable to LART[1] values of 15 to 46. The effects of hardness on crushing rate were not evaluated during these tests.

Jaw setting has a pronounced influence on crushing rate. The Denver Equipment Co. settings and capacities are shown in table 1.

Table 1.—Jaw settings and capacities

Jaw setting (inches)	*Capacity** (cu yd/hr**)
¼	.22
⅜	.37
½	.56
¾	.74
1	1.10
1-½	1.90
2	3.00
2-½	3.70

*These capacities are for crushing limestone.
**Average weight of material is 2,700 lb/yd^3.

Rock size affects crushing rate too. The crusher can accommodate rocks up to about 5 inches in diameter, but the closer the input rock size is to crushed rock size, the higher the crushing rate. Jaw wear also increases crushing rate. As the jaws wear, the opening increases, which has the same effect as increasing jaw setting.

The way an operator feeds the crusher influences production. At first, the typical operator selects the largest rock he can fit into the crusher. Several 5-inch diameter rocks will fill the hopper, but they lower the crushing rate. If the operator continues to work in the same spot, however, rocks of this size become scarce and smaller and smaller rocks are used until they are small enough to shovel into the crusher (fig. 6). The smaller rocks increase crushing rate.

New jaws were installed in the crusher at the beginning of the tests. After operating 22 hours the jaws showed considerable wear, so they were rotated. After 20 more hours (42 hours total), the crusher jaws and wedge were worn enough for replacement or resurfacing. Tests were not long enough to establish a wear rate for the cheek plates (replaceable wear surface). However, new cheek plates were installed at the side of the jaws during tests. New bolts were used; otherwise the heads of worn bolts not flush with the surface of the cheek plates would create a slight cavity where rocks could hang up and choke the crusher.

Hauling

Two hauling capacities were determined for each carrier: (1) the volume of crushed rock the carrier could haul and (2) the volume of crushed rock that could be obtained from a carrier load of whole rock. (Transforming whole rock into crushed increases its volume; for example, the Picus could carry only 8 cubic feet of crushed rock but enough whole rock to amount to 9 cubic feet when crushed.) The carriers were also weighed empty, filled with rock, and filled with crushed rock. Carrier capacities and weights are shown in table 2.

The gross weight of the Toter (1,880 pounds) seems high. The manufacturer says the Toter has carried loads up to 1,000 pounds and sets no load limit. This is the only crushing project where the Toter has been used, and it is doubtful it could handle that load continuously without excessive wear to the track and drive system.

The Picus typically has been used with few problems and can be considered a proven machine with outstanding reliability and performance features.

---
[1] LART (Los Angeles Rattler Test) value is a measure of rock resistance to abrasion (ref. ASTM Standard No. C131-64t).

Figure 6.–Crushing rock on forest trail.

Table 2.—Capacities and weights of carriers

	Capacity				Weight		
	Crushed rock obtained from load of rock		*Crushed rock*		*Empty*	*Loaded with rock*	*Loaded with crushed rock*
	(cu ft)	(cu yd)	(cu ft)	(cu yd)	(lb)	(lb)	(lb)
Picus	9.0	.333	8.0	.296	300	1,245	1,045
Toter	11.5	.426	11.0	.408	615	1,880	1,610

Table 3 lists average times required for two men to crush a load of rock hauled by each carrier and times required to crush enough rock to fill each carrier. For the Picus, times were taken on both trails; for the Toter, only on the North Shore Trail. These times are important to know when hauling round trips of more than 2,800 feet, because then, the crusher can easily stay ahead of the carriers in producing crushed rock.

Table 3.—Average time required to crush carrier load of rock and crush enough rock to fill carrier

	Crush carrier load of rock		*Crush enough rock to fill carrier*	
	(min)	(hr)	(min)	(hr)
Picus	18	.30	16	.27
Toter	23	.38	22	.37

The Picus was loaded with rock from slide areas, a dry streambed, and a lakebed; the Toter was loaded only from a slide area. Rock slides proved the best source. Rock was not only abundant, but was also usually piled high along the trail, making loading faster and easier. When crushed rock was used in the tests, it was shoveled into the carriers for hauling. Rock placed along the trail for crushing was unloaded by hand. Unloading time for crushed rock was so short — 15 to 20 seconds — that it was included in travel time (fig. 7). Table 4 shows average loading and unloading times for both carriers.

Table 4.—Average loading and unloading time for carriers

	Loading			
	Picus		**Toter**	
	1 man	*2 men*	*1 man*	*2 men*
Rock	-----	6 min. (0.10 h)	15 min. (0.25 h)	8 min. (0.13 h)
Crushed Rock	-----	2 min. (0.03 h)	6 min. (0.10 h)	3 min. (0.05 h)

	Unloading			
	Picus		**Toter**	
	1 man	*2 men*	*1 man*	*2 men*
Rock	-----	2.5 min. (0.04 h)	5 min. (0.08 h)	3 min. (0.05 h)
Crushed Rock	*----	*----	*----	*----

*Time to dump crushed rock was short — 15-20 seconds — and is included in travel time.

Figure 7.–Spreading crushed rock with Picus carrier.

Traveling

Travel speed is determined by how fast the operators can safely drive the equipment. Trail condition has the greatest influence on travel speed. On excellent trail the three machines could move faster than a man could walk. Soft shoulders, protruding rocks, outsloped treads, and steep sideslopes slowed travel speed and tested operator skill and judgment. Heavy loads and the machines' high center of gravity also slowed travel speed.

The three machines could climb slopes up to 20 percent.

On both trails, much handwork had to be done in spots so the machines could travel safely. Of the two trails, the Sleeping Child Trail was the rougher, having sideslopes of 100 percent, outsloped tread, 18 percent grades, and many protruding rocks and roots. In places, the trail was less than 18 inches wide, and often the crusher and Picus carrier had to be maneuvered carefully around boulders partially blocking the trail.

Because the Toter was not available for the Sleeping Child Trail, and conditions were considered unusually difficult there, travel speeds for all three pieces of equipment shown in table 5 were calculated on the North Shore Trail.

Table 5.—Average speeds for round trip travel

Item	*Speed* (mph)
Picus	2.79
Toter	1.98
Crusher	2.04

The slow travel speeds of the machines discourage driving them long distances to work sites. All can be moved to remote work sites by helicopter (Bell 47G-3B-1). Although the crusher was not actually flown to a job, it was disassembled into acceptable payloads in about 48 minutes and reassembled in 96 minutes.

SURFACING RATES

On the average, 1.11 cubic yards of rock per hour was crushed (with jaws set for ¾-inch opening) and spread. Until hauling distances became critical and affected overall performance, this amounted to a layer of crushed rock 24 inches wide and 2 inches deep being spread along 90 feet of tread each operating hour (fig. 8). Crusher rates can vary though, since a number of factors influence them: rock hardness; rock size, shape, and distribution; crusher jaw setting; condition of the crusher jaws; feeding techniques.

To minimize handling, it is usually faster to transport crushed rock. Ninety feet per hour was the best average rate that could be obtained. This rate depends on crusher performance and can be sustained until round trip haul distances exceed 2,800 feet with the Toter or 3,400 feet with the Picus (see fig. 8). The Toter has a slightly lower surfacing rate for some haul distances, but the difference is negligible.

To compute surfacing rates for specific jobs, mathematical equations are shown in the appendix.

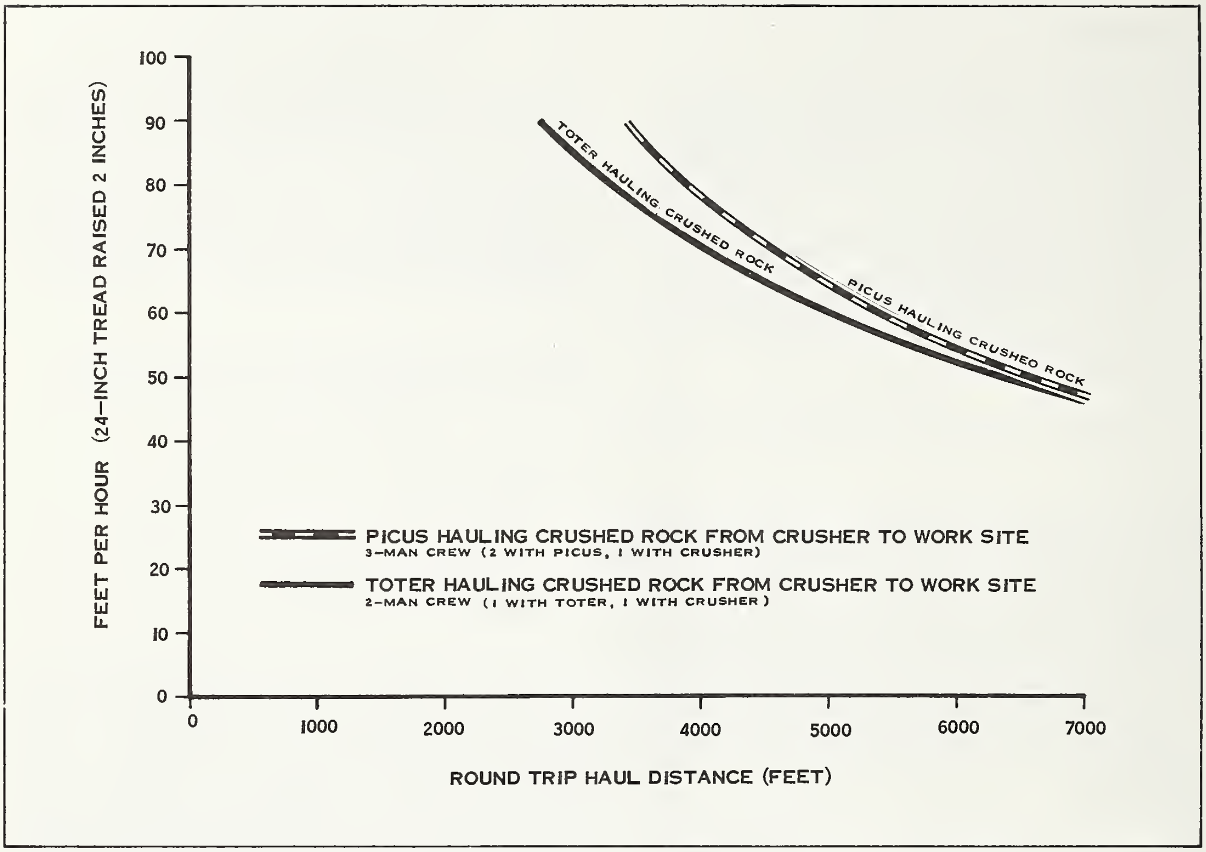

Figure 8.–Surfacing rates vs. round trip haul distance.

SURFACING COSTS

Surfacing costs per foot are found by dividing the amount of work performed, in this case the number of feet of tread covered with crushed rock in one hour, into equipment operating costs — depreciation, maintenance, fuel, labor.

The Center computed that it cost $14.53 an hour for a two-man crew to run the rock crusher and manually spread rock in place. This figure divided by 90 feet (length of trail tread crusher covers in an hour) results in a surfacing cost of 16 cents per linear foot of 24-inch trail. This might be typical of the costs to be incurred in surfacing trail near a slide area where rock is readily available, and no carrier is needed.

The Center figured the hourly cost of the Picus carrier at $11.05 and the Toter at $6.60. Surfacing costs in cents per foot using the carriers to haul crushed rock are shown in figure 9. Costs of these two methods vary, depending on how far the rock source is from the work site.

Data presented in figure 9 were obtained from a study of surfacing rates and operating costs only. Many costs associated with a typical field project were not estimated, such as "walking" the crusher long distances to a work site; preparing trail for crushing operations by drilling and blasting; crews traveling to and from work site; overhead and repairs, and consideration that only 5 machine hours can be obtained in an 8-hour work day at best. As a result, surfacing costs on field projects are likely to be higher.

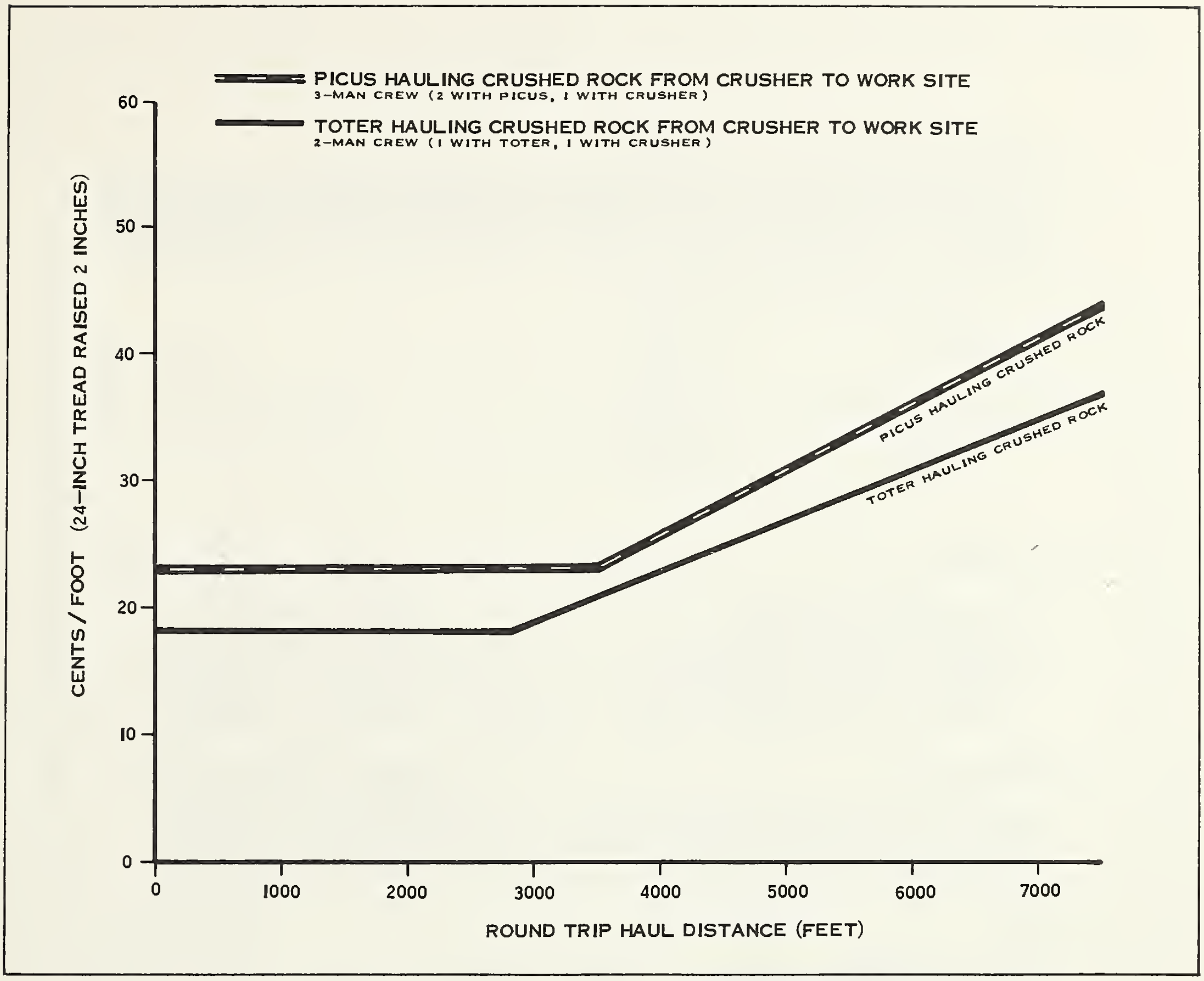

Figure 9.–Surfacing costs vs. round trip haul distance.

Past experience bears this out. Earlier models of these machines were used on the Okanogan and Lolo National Forests in the 1960's and surfacing costs were higher than those developed in the tests under study in this report.

A rock crusher was used on the Winthrop District of the Okanogan National Forest in 1969 to crush rock laying along the trail. Surfacing costs were 28 cents per foot. Since the crusher was on loan, initial cost, salvage value, and depreciation were costs not included.

Figure 9 indicates that hauling crushed rock with the Picus carrier 250 feet round trip costs 24 cents per foot. In 1969, a portion of a trail on the Plains District, Lolo National Forest, was surfaced under similar conditions. Applying the crushed rock there cost 26 cents per foot. Costs of repairs, preparing trail, overhead, and walking machines about 5 miles were not considered.

The difference between test costs and actual field costs emphasizes the importance of preparing thorough cost estimates. The surfacing costs discussed here are only some of many costs involved in an actual field project.

Costs of crushed rock produced by the self-propelled rock crusher are high when compared to crushed rock purchased from commercial sources. Nevertheless, crushed rock is a relatively cheap, fast method of increasing trail tread life and reducing maintenance costs.

Operating Costs — Rock Crusher

Operating costs are based on depreciating the machine over a 10-year period and a 4,000-hr life expectancy. Actual maintenance costs included replacing the crusher jaws, cheek plates, wedge, and bolts. These parts have an estimated life of 42 hours, according to test results.

Initial Cost:	$5,000	
Salvage Value (10%):	−500	
	$4,500	

Depreciation:

10 yr @ $450/yr = $4,500 estimated 4,000-h life of machine = 4,000 h ÷ 10 yr = 400 h/yr ∴ ($450/yr) ÷ (400 h/yr) = $1.13/h	$1.13/h

Maintenance:

Estimated from past experience using similar equipment = $3.00/h	$3.00/h

Fuel:

Fuel consumption 1 gal/h @ $0.40/gal = $0.40/h	$0.40/h

Labor:

1 man @ $5.00/h	$5.00/h

TOTAL OPERATING COST	(1 man)	*$9.53/h*
	(2 men)	*$14.53/h*

Operating Costs — Carriers

Both carriers are depreciated over a 5-year period and an estimated 1,500-hour life. Labor costs include two men to run the Picus carrier and one man to run the Toter.

	Picus Carrier	*Toter Carrier*
Initial Cost:	\$1,000	\$1,500
Salvage Value (10%):	−100	−150
	\$ 900	\$1,350
Depreciation:		
5 yr @ \$180/yr = \$900 estimated 1,500-h life of machine = 1,500 h ÷ 5 yr = 300 h/yr ∴ (\$180/yr) ÷ (300 h/yr) = \$0.60/h	\$ 0.60/h	
5 yr @ \$270/yr = \$1,350 estimated 1,500-h life of machine = 1,500 h ÷ 5 yr = 300 h/yr ∴ (\$270/yr) ÷ (300 h/yr) = \$0.90/h		\$ 0.90/h
Maintenance:	\$ 0.25/h	\$ 0.50/h
Fuel:		
Fuel consumption ½ gal/h @ \$0.40/gal = \$0.20/h	\$ 0.20/h	\$ 0.20/h
Labor:		
2 men @ \$10.00/h	\$ 10.00/h	
1 man @ \$5.00/h		\$ 5.00/h
TOTAL OPERATING COST	*\$ 11.05/h*	*\$ 6.60/h*

CONCLUSIONS

Crushing rock laying along the trail proved to be the fastest and cheapest method for surfacing forest trails. The main limitation is that rock must be plentiful along the trail. Next in efficiency was crushing rock, then hauling and spreading it. The most costly method was hauling rock, then crushing it.

Trail condition strongly influences surfacing rate. The better the trail tread, the faster the carriers can travel, and the higher the surfacing rate. Haul distances should be kept as short as possible.

The crusher and carriers have proven themselves sturdy and practical in tests and actual field use.

APPENDIX

Equations for Finding Surfacing Rates

Until the material must be transported long distances (see fig. 8), the surfacing rate (R) can be calculated by multiplying the linear feet of tread that can be surfaced by 1 cubic yard of material (L) times the number of cubic yards the crusher can produce per hour (V). In general form, the equation is:

$$R = L \times V$$

When the time (in hours) required to haul (T_1), plus the time (in hours) required to load and unload (T_2), exceeds the time required to crush a carrier load of material (table 3), the surfacing rate can be calculated by this equation:

$$R = L \times T_3 \div (T_1 + T_2)$$

Values for L vary with the width of the tread and the depth of surfacing. For 2-inch depths and 24-inch widths (dimensions used in the tests), L = 81 linear feet per cubic yard. Values for T_3, average time (in hours) required to crush carrier load of rock and crush enough rock to fill carrier, can be found in table 3.

Values for V depend on jaw setting and rock hardness. Table 1 shows the various crusher rates for crushing limestone. During these tests, average crushing rates were 1.11 cubic yards per hour (for ¾-inch jaw setting).

By knowing the haul distance, values for T_1 can be calculated from table 5; values for T_2 can be obtained from table 4.

GPO 886-503

NATIONAL FOREST SYSTEM · COOPERATIVE FORESTRY · FORESTRY RESEARCH

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

U S D A FOREST SERVICE EQUIPMENT DEVELOPMENT CENTER missoula